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C65-9626

CONTRACT REQUIREMENTS	CONTRACT ITEM	MODEL	CONTRACT NO.	DATE
Exhibit E, Para. 5.2	023	LEM	NAS 9--1100	

Type II

LEM PROJECT
ENGINEERING FILE

Primary No. 761

REPORT

NO. LED-550-12 DATE: 10-22-1963

Electrical Power Subsystem Power Generation Configuration Study

[U]

CODE 26512

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REVISIONS

DATE	REV. BY	REVISIONS & ADDED PAGES	REMARKS

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ENG. 345

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

1.1 Summary

There were 19 configurations considered for this study. The results are summarized in Table 1.

Configuration 1 is the current status configuration. It consists of: 3 fuel cells, 2 spiking batteries, and staged tankage.

The other 18 configurations are in groups of 3. In each group the configurations vary by varying the combination of staged and unstaged tankage. The variation from group to group is by a switch in number of fuel cells or batteries etc.

The transition from 3 fuel cells and no backup battery to 2 fuel cells and a backup battery shows a marked improvement in the crew safety reliability. The main reason for this transition is an additional parallel path that the backup battery provides. In addition a slight improvement in mission success should also be found, because of the reliability improvement of a battery over a fuel cell. This can best be seen by comparing the mission success reliability of 2 of 3 fuel cells with 2 of 3 (3=2 F.C.A. & 1 Batt.) in Table 2.

There are 2 groups of configurations with 2 fuel cells and a backup battery. The first set (configuration 5-7) has fat hydrogen tankage (2 tanks in the ascent stage). While the second set (configuration 8-10) has lean hydrogen tankage (1 tank in the ascent stage). While fat tankage adds redundancy for crew safety and consequently improves the reliability, for mission success it has the opposite effect. Since either tank can fail and cause an abort of the mission, it will lower the mission success reliability.

In making the transition to 1 fuel cell, crew safety can be maintained by using 2 backup batteries, however, since the reliability of 1 fuel cell is so low, the mission success reliability is severely hampered.

In reviewing the mission success numbers, it appears that an upper limit exists for mission success.

This is due to the fact that in all configurations for mission success the tankage is in series. To improve the reliability for mission success requires improving the mission success reliability for the tankage.

Mission success reliability for the tankage can be improved with a change in the ground rules. LMO-540-134 states that, "the fuel for the fuel cells...should provide the capability to operate at minimum acceptable power levels during the maximum orbital contingency time.

1.1 Summary (continued)

If the fuel cells operate at a level of degradation greater than the design limits, the lunar stay time should be commensurately reduced." This ground rule has the effect of placing the hydrogen fat tanks in series instead of in parallel.

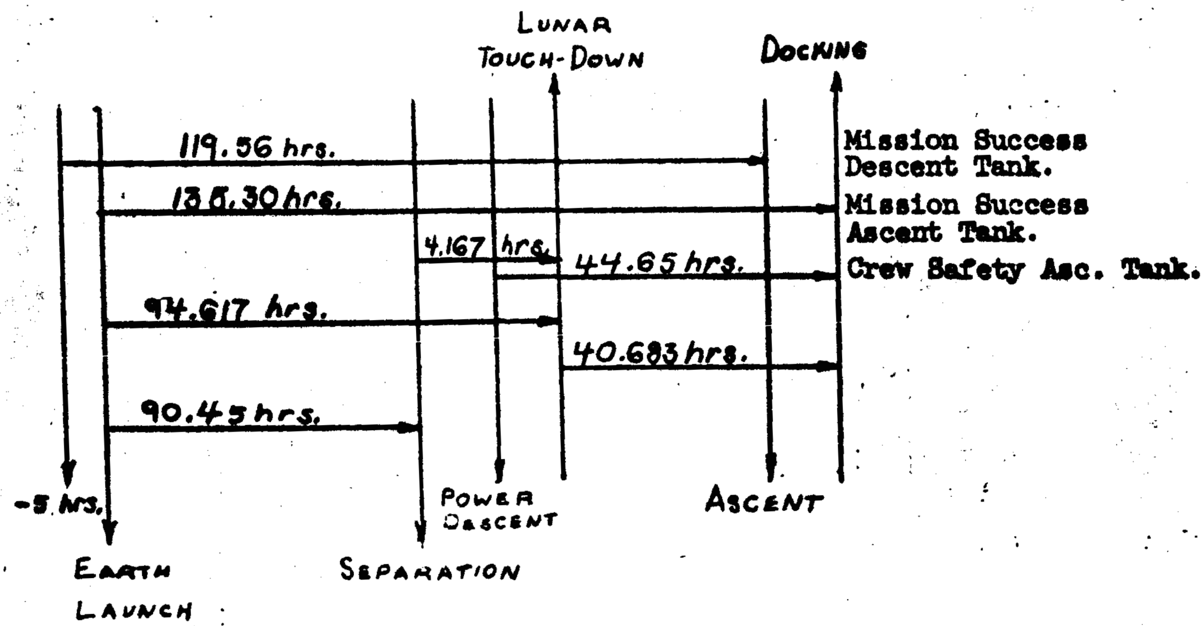
1.2 Failure Rates

The failure rates used for this study are summarized in Table 3.

1.3 Equivalent Operating Times

There are two basic approaches to use in adjusting Reliability to conform to boost and non-boost environments. Either an adjustment of the failure rate or an adjustment in the operating time can be used. In compliance with LMO-550-37 an adjustment in the operating time is used here.

It is assumed throughout that a constant failure rate over the entire mission time is to be considered. Consequently for crew safety 44.65 hours is the equivalent operating time and it concerns only the ascent tanks, i.e. it is not necessary for the descent tank to operate for crew safety. However, for mission success, the descent tanks must operate as well as the ascent tanks.



Conf #	Fuel Cells Quan	Fuel Cells Unit Power (Watts)	Fuel Cells Unit Weight (lbs.)	Battery Quan	Battery Unit Energy (kw-Hrs)	Battery Unit Weight (lbs.)	Tankage O_2 Quan	Tankage O_2 Conf. w/GOX	Tankage H_2 Quan	Tankage H_2 Conf.	Reliability Crew Safety	Reliability Mission Success	Power Distr. Weight	Earth Launch Weight	Sep. Weight	Ascent Weight Normal Mission	Total Effect Weight
1	3	900	70	2	0.425	8.5	3	ST	3	ST	.9997441	.9802611	91.4	675.8	650.3	478.7	3683
2	3	900	70				3	ST	3	ST	.9997441	.9802611	91.4	656.8	633.3	461.7	3570
3	3	900	70				3	ST	2	Unst.	.9997495	.9827335	91.4	638.4	613.0	498.1	3653
4	3	900	70				2	Unst.	2	Unst.	.9997884	.9856921	91.4	636.9	611.4	540.6	3812
5	2	1250	75	1	2.0	55	3	ST	3	ST	.99999747	.9802648	94.2	638.9	614.6	448.8	3467
6	2	1250	75	1	2.0	55	3	ST	2	Unst.	.99999750	.9827371	94.2	617.9	594.3	482.8	3531
7	2	1250	75	1	2.0	55	2	Unst.	2	Unst.	.99999760	.9856958	94.2	615.7	592.0	523.7	3692
8	2	1250	75	1	2.0	55	3	ST	2	ST	.9999923	.9819296	94.2	621.4	597.8	431.9	3354
9	2	1250	75	1	2.0	55	3	ST	1	Unst.	.9999926	.9842758	94.2	603.7	580.2	468.6	3446
10	2	1250	75	1	2.0	55	2	Unst.	1	Unst.	.9999927	.9872391	94.2	593.1	569.5	501.1	3541
11	1	2500	111	1	2.0	55	3	ST	2	ST	.9999164	.9617332	79.5	560.7	538.5	371.8	2955
12	1	2500	111	1	2.0	55	3	ST	1	Unst.	.9999166	.9640312	79.5	543.2	521.0	409.8	3052
13	1	2500	111	1	2.0	55	2	Unst.	1	Unst.	.9999168	.9669335	79.5	532.5	510.3	441.8	3145
14	1	2500	111	2	2.0	55	3	ST	2	ST	.9999996	.9652917	105.3	641.5	619.3	452.6	3495
15	1	2500	111	2	2.0	55	3	ST	1	Unst.	.9999996	.9675981	105.3	624.0	601.8	490.6	3592
16	1	2500	111	2	2.0	55	2	Unst.	1	Unst.	.9999997	.9705111	105.3	613.3	591.1	522.6	3685
17	3	900	70	1	2.0	55	3	ST	3	ST	.999999053	.9815273	104.4	726.8	701.3	529.8	4024
18	3	900	70	1	2.0	55	3	ST	2	Unst.	.999999073	.9840028	104.4	706.4	681.0	566.1	4107
19	3	900	70	1	2.0	55	2	Unst.	2	Unst.	.999999217	.9869653	104.4	704.9	679.4	608.6	4267

TABLE 1

TABLE 2

Components	Crew Safety Reliability	Mission Success Reliability	Used in Configuration
H_2 Fat Tankage			
Staged	.9999925	.98933303	4,7
Unstaged	.9999979	.99182828	1,2,3,5,6
H_2 Lean Tankage			
Staged	.9985972	.993838568	10,13,16
Unstaged	.9986749	.9962132	8,9,11,12,14,15
O_2 Staged	.9997599	.99212402	3,4,6,7,9,10,12 13,15,16
Unstaged	.9997988	.9951109	1,2,5,8,11,14
FCA 1 Unit	.979	.979	11-16
2 Parallel Units	.999559	.999559	5-10
3 Parallel Units	.9999917	-	1-4
Emergency Battery	.9963	.9963	5-16
2 of 3 Fuel Cells	-	.9986960	1-4
2 of 3 (2 FCA & 1 Battery)	-	.9986997	5,6,7
2 Parallel FCA & Emergency Battery	-	.9958606317	8,9,10
1 FCA & Emergency Battery	-	.9753777	11,12,13
1 FCA & 2 Emergency Battery	-	.978986597	14,15,16
3 of 4 (3 FCA & 1 Battery)	-	.9999859467	17,18,19

TABLE 3

Item	Failure Rate (L)	Source
Tank	2.0×10^{-6}/hr	1
Tank Heater	3.0 "	2
Fill Valve	7.0 "	3
Cap	2.0 "	1
Vent Valve	7.0 "	3
Manual Switch	0.5 "	6
Pressure Switch	84.0 "	5
Pressure Transducer	300.0 "	7
Temperature Sensor	286.0 "	4
Quantity Sensor	300.0 "	7
Relief Valve	95.0 "	4
Lines & Fittings (1 Line & 2 Fittings)	0.54 "	1
Heat Exchanger	2.8 "	4
Check Valve	52.0 "	3
Shut-Off Valve (Solenoid)	85.0 "	4
Shut-Off Valve (Manual Override)	1.0 "	7
Quick Disconnect (Pyro)	R= .9999	8

Sources:
1) Aerojet General
2) Honeywell Ref: 31
3) Honeywell Ref: 52
4) Honeywell Ref: 63
5) Honeywell Ref: 64
6) Honeywell Ref: 120
7) Estimated
8) Conax Corporation No. 1830-1

2.1 Crew Safety

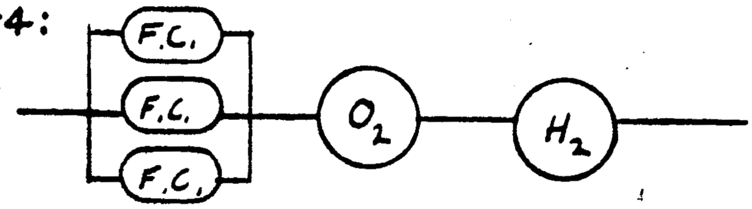
For crew safety the block diagrams are given on the next few pages (2.2). The values of the various blocks are listed in Table 2.

The reliabilities of the six tankage configurations (2.3) follow the block diagrams. The tankage configuration studied were: 1) unstaged O_2, 2) staged O_2, 3) unstaged Fat H_2, 4) staged Fat H_2, 5) unstaged Lean H_2, and 6) staged Lean H_2. The various ground rules, necessary for these configurations, are given with each configuration.

Following the section on the tankage configurations, is the section on basic tank configurations (2.4), which are a part of the tankage configurations.

2.2 Crew-Safety E.P.S. Configuration Analysis

Config. 1-4:



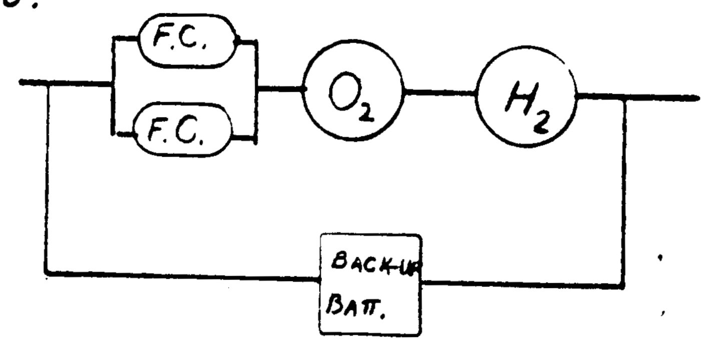
$$R = R_{3\,\text{Parallel F.C.}} \times R_{O_2} \times R_{H_2}$$

Config 1+2: $R = .999\,744\,1$

" 3 : $R = .999\,749\,5$

" 4 : $R = .999\,788\,4$

Config 5-10:



$$R = 1 - [(1 - R_{2\,\text{Parallel F.C.}} \times R_{O_2} \times R_{H_2})\, Q_{\text{BATT.}}]$$

Config 5: $R = .99999747$

6: $R = .99999750$

7: $R = .99999760$

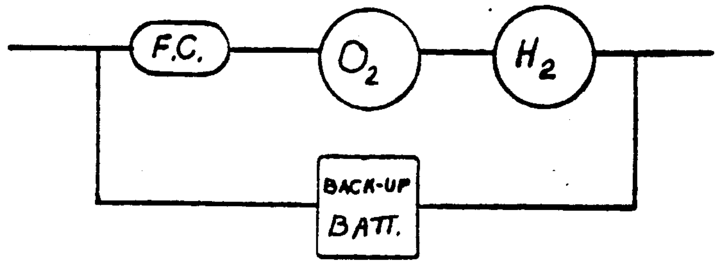
8: $R = .9999923$

9: $R = .9999926$

10: $R = .9999927$

CREW-SAFETY E.P.S. ANALYSIS CONT.

CONFIG. 11-13 :



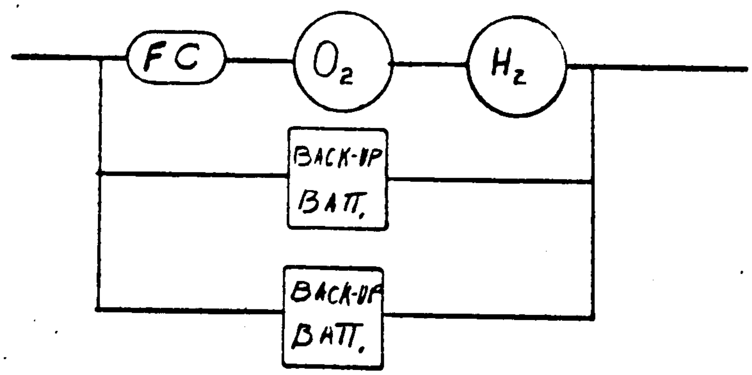
$$R = 1 - [(1 - R_{1F.C.} \times R_{O_2} \times R_{H_2})\, Q_{BATT.}]$$

CONFIG 11 : $R = .9999164$

12 : $R = .9999166$

13 : $R = .9999168$

CONFIG 14-16 :



$$R = 1 - [(1 - R_{1F.C.} \times R_{O_2} \times R_{H_2})\, Q_{BATT}\, Q_{BATT}]$$

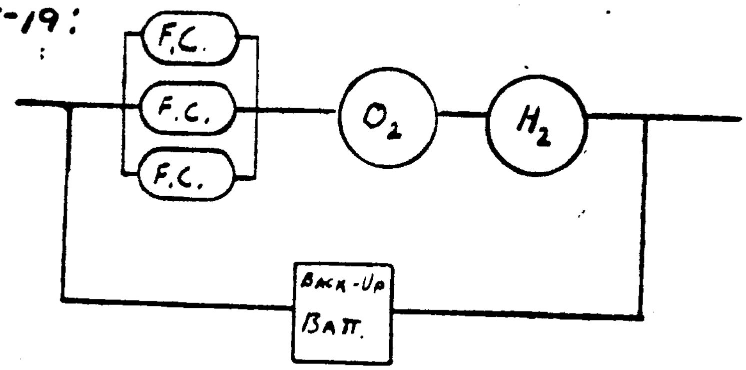
CONFIG 14 : $R = .9999996$

15 : $R = .9999996$

16 : $R = .9999997$

CREW-SAFETY E.P.S. ANALYSIS CONT.

CONFIG 17-19:



$$R = 1 - \left[\left(1 - R_{3\ \text{PARALLEL F.C.}} \times R_{O_2} \times R_{H_2}\right) Q_{BATT.} \right]$$

CONFIG 17: R = .999 999 053

18: R = .999 999 073

19: R = .999 999 217

FAT TANKAGE STAGED H_2 CONFIGURATION

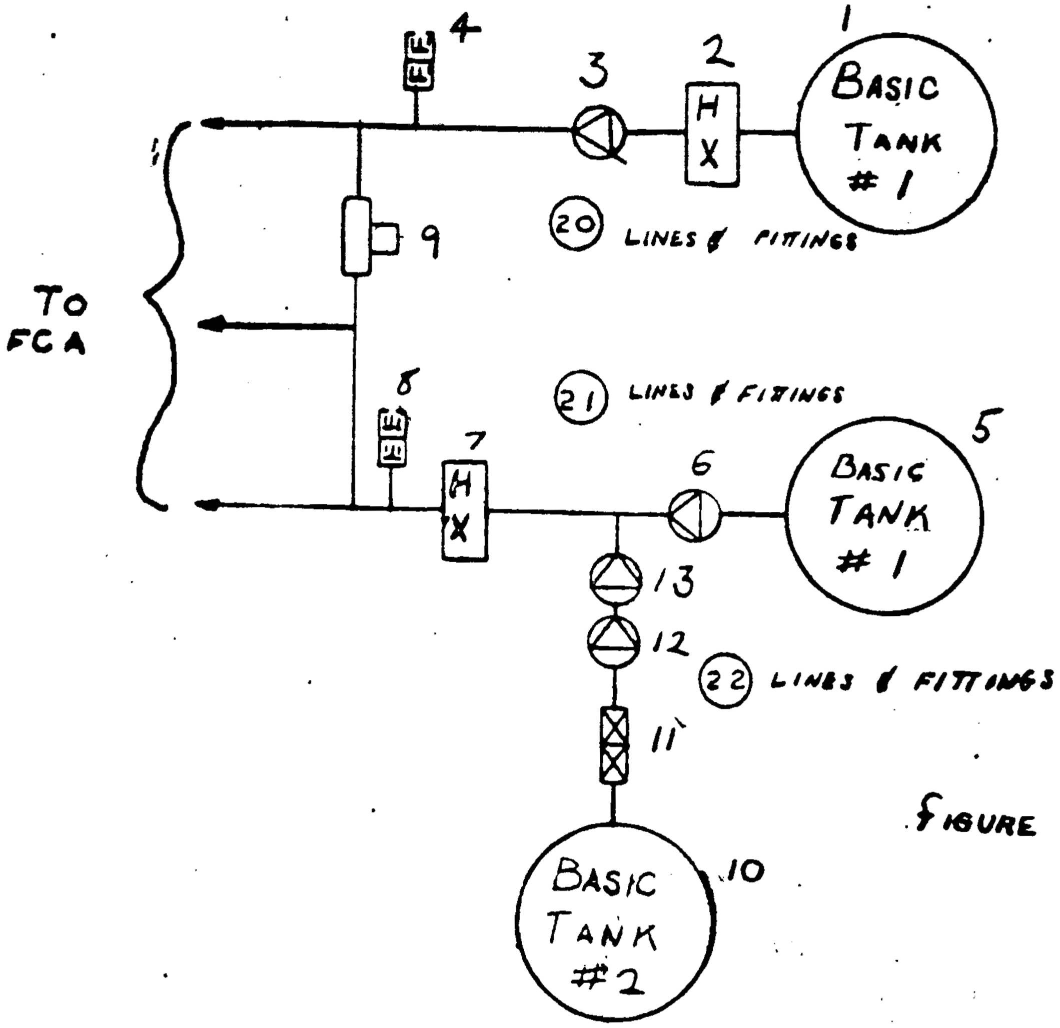


FIGURE 1

FAT TANK UNSTAGED H_2 CONFIGURATION

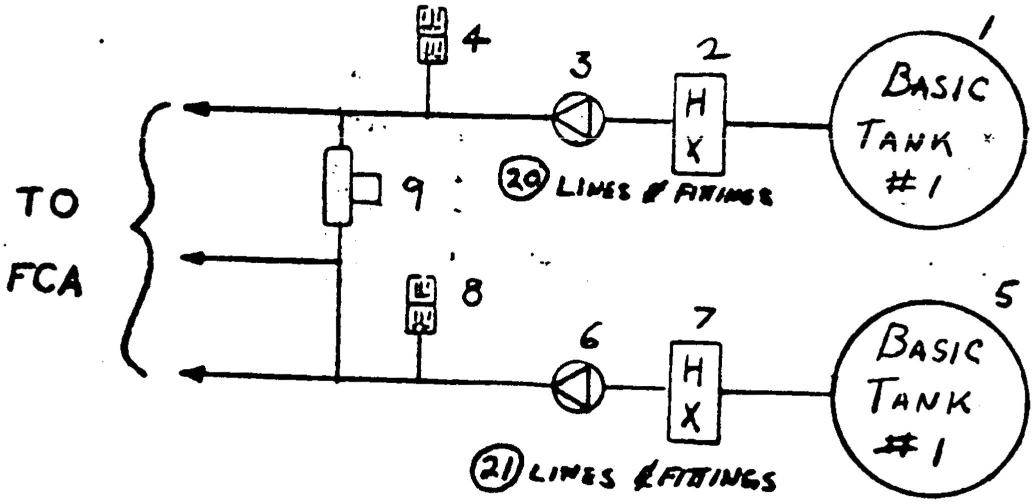


FIGURE 2

2.3.1 Fat Tank Unstaged H_2 Crew Safety Reliability

A reliability box diagram for Figure 2 can not be made without taking some liberties. However, by tracing through the success paths a lower bound on the reliability may be obtained (see LER-550-3).

First we must consider the most prevalent modes of failure. Failure in the tankage, heat exchanges lines and fittings and relief valves will cause leaks to the outside. Failures in the check valves will not check the flow of fluid in one direction. Failure in the normally open shut-off valve (part #9) will be improper closing or sealing.

There are two major success paths: 1) that of tank #1, and 2) that of tank #5. The path of tank #1 will have part 20 for its lines and fittings factor and the path of tank #5 will have part 21 for its lines and fittings factor.

2.3.1.1 Minimal Success Paths

1, 2, 4, 9, 20

1, 2, 4, 6, 8, 20

1, 2, 4, 5, 7, 8, 20, 21

3, 4, 5, 7, 8, 21

5, 7, 8, 9, 21

2.3.1.2 Minimal Cuts

(1-3-9) (1-5) (1-7) (1-8) (1-21) (2-3-9) (2-5) (2-7) (2-8) (2-21) (4-5) (4-7) (4-8) (4-9) (4-21) (9-5-6) (9-6-7) (9-6-21) (9-8) (20-5) (20-7) (20-8) (20-9) (20-21)

2.3.1.3

$$R = 1 - (Q_1Q_3Q_9 + Q_1Q_5 + Q_1Q_7 + Q_1Q_8 + Q_1Q_{21} + Q_2Q_3Q_9 + Q_2Q_5 + Q_2Q_7 + Q_2Q_8 + Q_2Q_{21} + Q_4Q_5 + Q_4Q_7 + Q_4Q_8 + Q_4Q_9 + Q_4Q_{21} + Q_9Q_5Q_6 + Q_9Q_6Q_7 + Q_9Q_6Q_{21} + Q_9Q_8 + Q_{20}Q_5 + Q_{20}Q_7 + Q_{20}Q_8 + Q_{20}Q_9 + Q_{20}Q_{21})$$

Where: 1) $Q_n = L_n t$ & $t = 44.65$ Hours

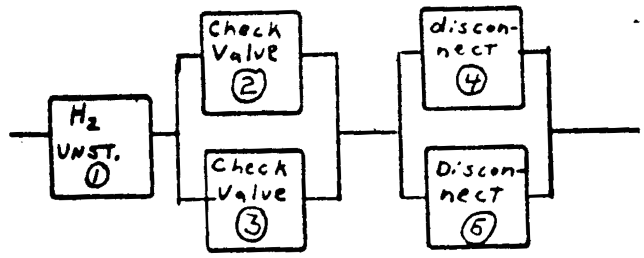
2) $L_{20} = L_{21} = (0.54 \times 10^{-6}) \times (5 \text{ parts}) \times (1.5) = 4.05 \times 10^{-6}$

2.3.1.4

$\therefore R = .9999979$

2.3.2 Fat Tank Staged H_2 Crew Safety Reliability

An approximation will be used here to obtain the reliability of Figure 1. Basically the staged system can be simplified to a box diagram. It consists of the unstaged system in series with 2 check valves and in series with a double quick disconnect pyro device.



$$R = R_1 (1 - Q_2 Q_3)(1 - Q_4 Q_5)$$

$$R = .9999925$$

Where $Q_n = (\lambda_n) \times (t)$ & $t = 44.65$ Hours

LEAN STAGED H_2 CONFIGURATION

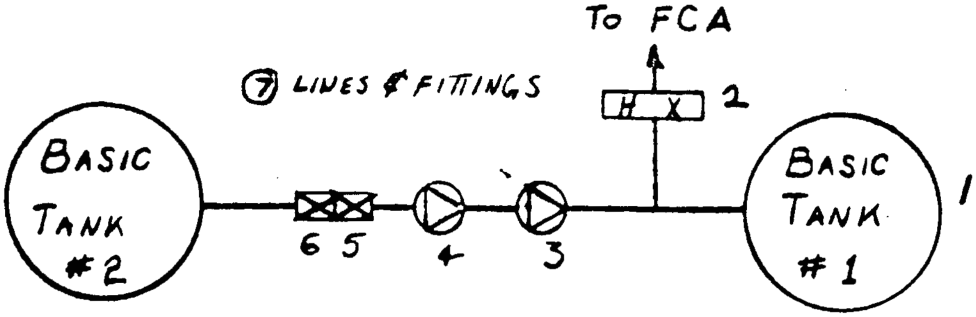


FIGURE 3 A

LEAN UNSTAGED H_2 CONFIGURATION

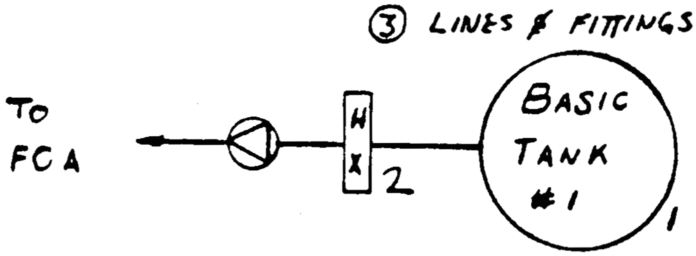
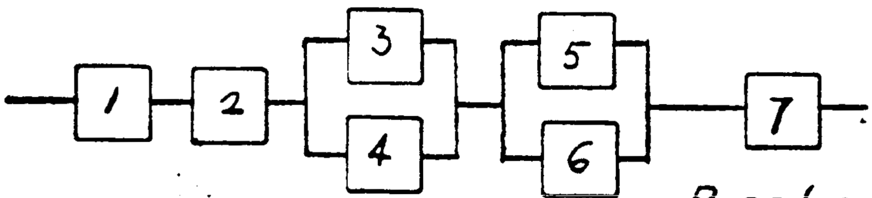


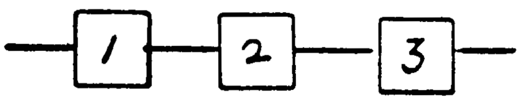
FIGURE 4 A

CREW-SAFETY RELIABILITY DIAGRAMS



$$R = R_1 R_2 (1 - Q_3 Q_4)(1 - Q_5 Q_6) R_7$$

FIGURE 3 B



$$R = R_1 R_2 R_3$$

FIGURE 4 B

2.3.3 Lean Tank Unstaged H_2 Crew Safety Reliability

This configuration is shown in Figure 4A. The reliability box diagram is shown in Figure 4B. The reliability is simply:

$$R = R_1R_2R_3 = .9986749$$

2.3.4 Lean Tank Staged H_2 Crew Safety Reliability

This configuration is shown in Figure 3A. The reliability box diagram is shown in Figure 3B. The reliability is simply:

$$R = R_1R_2(1-Q_3Q_4)\ (1-Q_5Q_6)\ R_7 = .9985972$$

STAGED O_2 CONFIGURATION

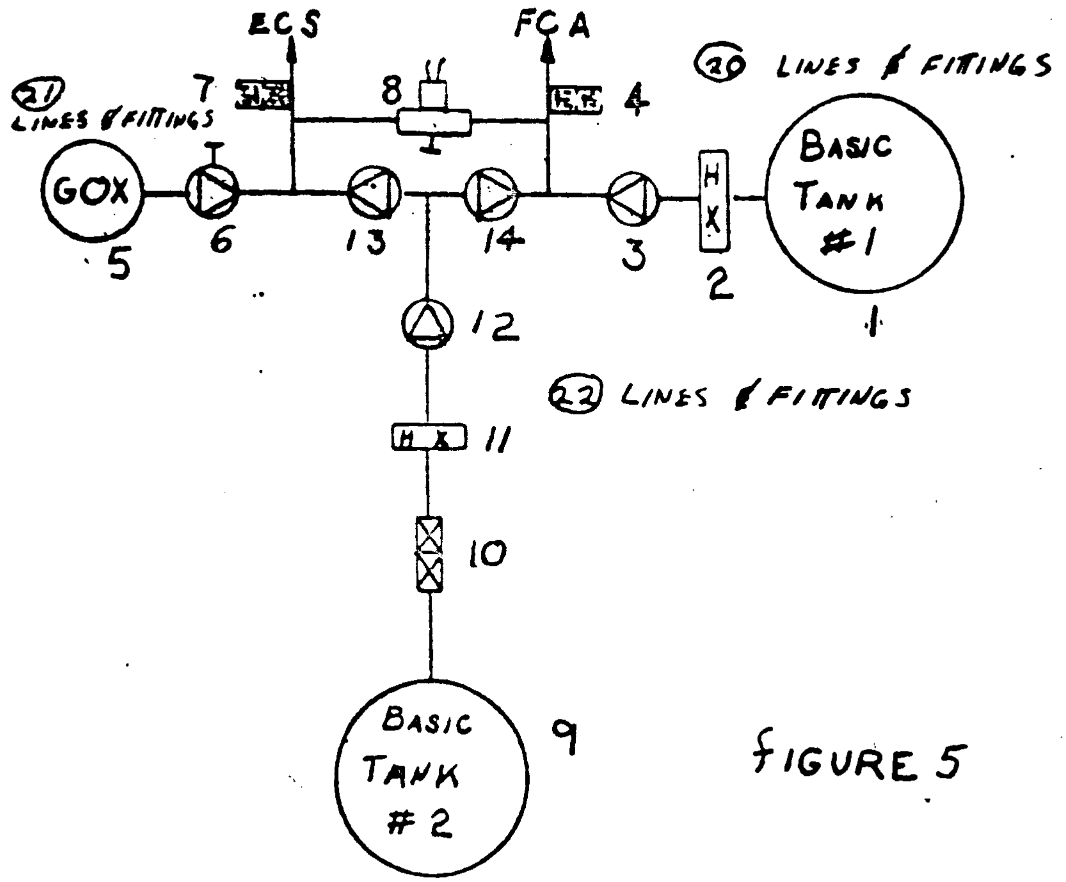


FIGURE 5

UNSTAGED O_2 CONFIGURATION

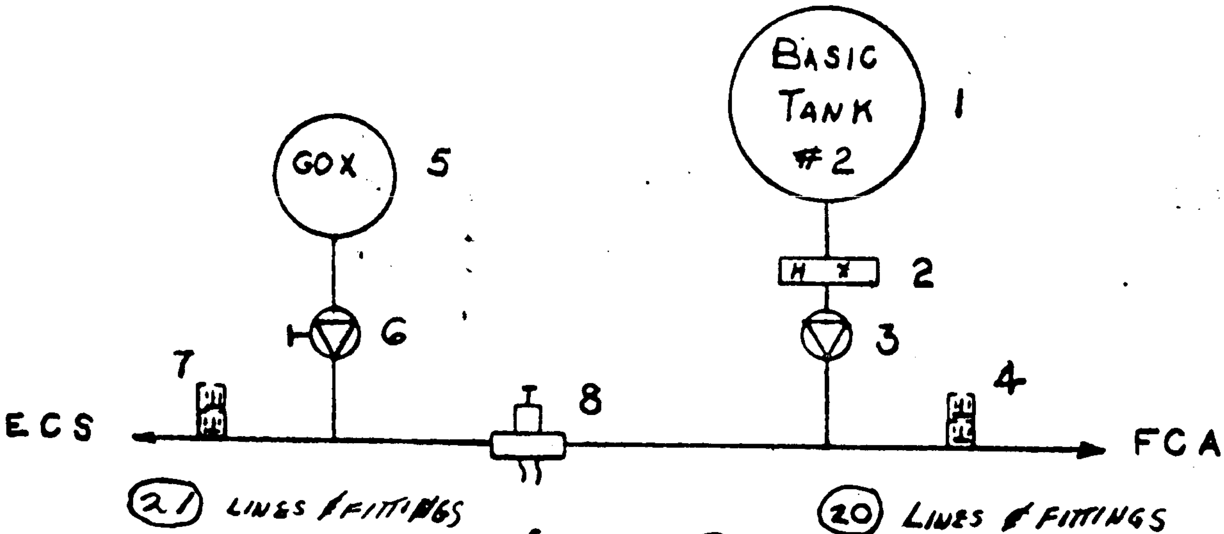


FIGURE 6

2.3.5 Unstaged O_2 Crew Safety Reliability

Here again, as in the hydrogen system, we can not obtain a simple box diagram for Figure 6. But, by tracing through the minimal success paths a good lower board on the reliability can be obtained (see LER-550-3).

The most prevalent modes of failure for all the parts must first be considered. Failures in tankage, heat-exchangers, relief valves, and lines and fittings will cause a leak to the outside. Failures in the check valves will not check the flow of fluid in one direction. Failure in shut-off valve (part 8) will be improper opening or closing.

There are two major success paths: 1) that of the super-critical tanks (part 1), and 2) that of the paseous tank (part 5). The path of the part #1 tank will have part 20 included for its lines and fittings factor. The path of the part #5 tank will have part 21 included for its lines and fittings factor.

2.3.5.1 Minimal Success Paths

1, 2, 4, 8, 20

1, 2, 4, 6, 7, 20, 21

1, 2, 4, 5, 7, 20, 21

3, 4, 5, 7, 8, 20, 21

2.3.5.2 Minimal Cuts

(4) (20) (1-3) (1-5) (1-7) (1-8) (1-21) (2-3) (2-5) (2-7) (2-8) (2-21) (8-7) (8-6-5) (8-21)

2.3.5.3

$$R = R_4 R_{20} \Big[(1-Q_1Q_3)(1-Q_1Q_5)(1-Q_1Q_7)(1-Q_1Q_8)(1-Q_1Q_{21}) (1-Q_2Q_3)(1-Q_2Q_5)(1-Q_2Q_7)(1-Q_2Q_8)(1-Q_2Q_{21}) (1-Q_8Q_7)(1-Q_8Q_6Q_5)(1-Q_8Q_{21}) \Big]$$

Where:

1) $R_n = 1 - Q_n$

2) $Q_n = L_n \times t$; $t = 44.65$ Hours

3) $L_{20} = L_{21} = (0.54 \times 10^{-6}/\text{hr}) \times (5 \text{ parts}) \times (1.5 \text{ lines \& fittings/part}) = 4.05 \times 10^{-6}$

4) $Q_8 = L_8 \times (15 \text{ cycles}) = .0000001$

2.3.5.4 $\therefore$ R = .9997988

2.3.6 Staged O_2 Crew Safety Reliability

For crew safety we need not consider the descent tank in Figure 5. Here again, as in the unstaged configuration, we must resort to a minimal success paths technique to obtain a lower bound in the reliability (see LER-550-3).

It is necessary to note the most prevalent modes of failure. Failures in the tankage, heat exchangers, lines and fittings and relief valves will cause leaks to the outside. Failures in the check valves will not check the flow of fluid in one direction. Failure in the shut-off valve (part 8) will be improper opening or closing.

There are three major tank paths. Tank part #1 has part #20 for its line and fittings factor. Tank part #5 has part #21 for its lines and fittings factor. And Tank part #9 has part #22 for its lines and fittings factor.

2.3.6.1 Minimal Success Paths

1, 2, 4, 8, 10, 14, 20
3, 4, 5, 7, 8, 10, 13, 14, 20, 21
3, 4, 5, 7, 8, 10, 12, 20, 21, 22
1, 2, 4, 6, 7, 10, 13, 14, 20, 21
1, 2, 4, 6, 7, 10, 12, 20, 21, 22
1, 2, 4, 5, 7, 10, 13, 14, 20, 21
1, 2, 4, 5, 7, 10, 12, 20, 21, 22

2.3.6.2 Minimal Cuts

(4) (10) (20) (1-3) (1-5) (1-7) (1-8) (1-12-13) (1-13-22) (12-14) (14-22) (1-21) (2-3) (2-5) (2-7) (2-8) (2-12-13) (2-13-22) (7-14) (14-21) (2-21) (5-6-8) (7-8) (8-12-13) (8-13-22) (8-21)

2.3.6.3

$$R = R_4 R_{10} R_{20} \left[1-(Q_1Q_3 + Q_1Q_5 + Q_1Q_7 + Q_1Q_8 + Q_1Q_{12}Q_{13} + Q_1Q_{13}Q_{22} + Q_{12}Q_{14} + Q_{14}Q_{22} + Q_1Q_{21} + Q_2Q_3 + Q_2Q_5 + Q_2Q_7 + Q_2Q_8 + Q_2Q_{12}Q_{13} + Q_2Q_{13}Q_{22} + Q_7Q_{14} + Q_{14}Q_{21} + Q_2Q_{21} + Q_5Q_6Q_8 + Q_7Q_8 + Q_8Q_{12}Q_{13} + Q_8Q_{13}Q_{22} + Q_8Q_{21})\right]$$

2.3.6.3 (continued)

Where: 1) $R_n = 1 - Q_n = 1 - (L_n \times t)$ & $t = 44.65$ Hours

2) $L_{20} = L_{22} = (0.54 \times 10^{-6}) \times (6 \text{ parts}) \times (1.5) = 4.86 \times 10^{-6}$

3) $L_{21} = (0.54 \times 10^{-6}) \times (5 \text{ parts}) \times (1.5) = 4.05 \times 10^{-6}$

4) $Q_8 = L_8 \times (15 \text{ cycles}) = 1.0 \times 10^{-8}$

2.3.6.4 $\therefore$ R = .9952414

BASIC TANK DESIGN
No. 1

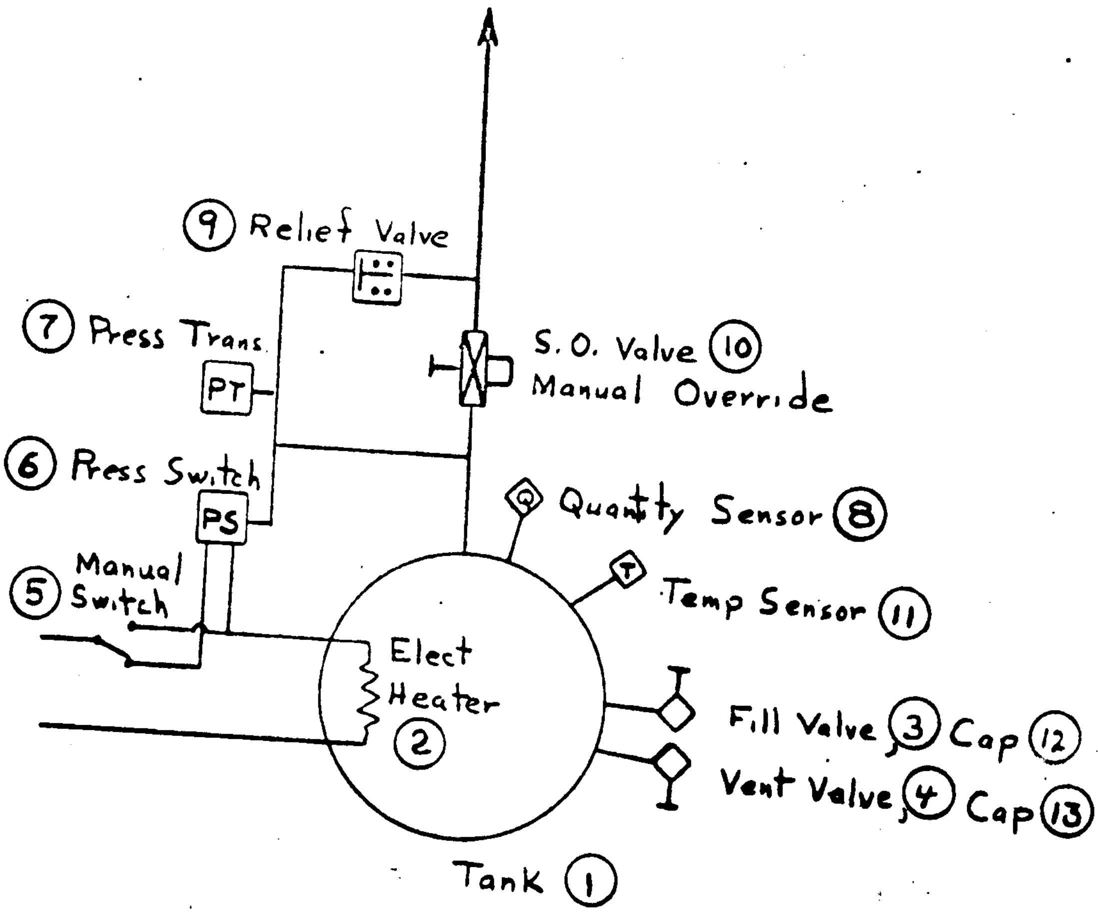


Figure 7

BASIC TANK DESIGN
No. 1
RELIABILITY DIAGRAM

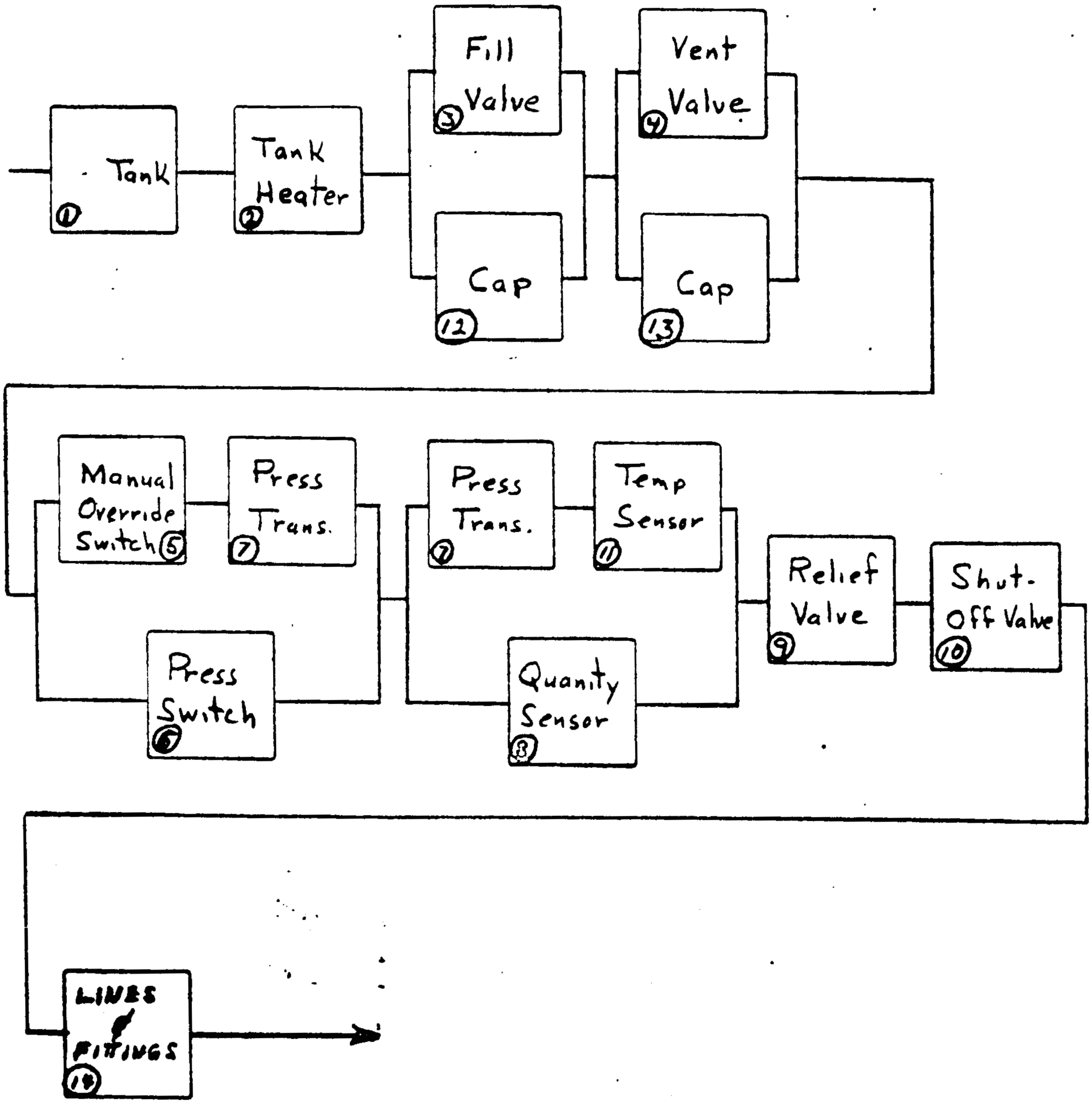


Figure 8

2.4.1 Basic Tank Design # 1 Part Unreliabilities for Crew Safety

This tank, Figure 7 is used in the ascent stage for all four hydrogen configurations and in the ascent stage for the staged oxygen. All failure rates are per million hours or per million cycles of operation. An approximation used is:

$Q_n = (L_n) \times (t).$ where t= 44.65 Hours

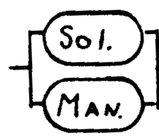
$Q_1 =$	89.3×10^{-6}	$Q_8 = 13395.0$	$\times 10^{-6}$
$Q_2 =$	133.95×10^{-6}	$****Q_9 =$ 0.0	$\times 10^{-6}$
$Q_3 =$	312.55×10^{-6}	$**Q_{10} =$ 0.01925	$\times 10^{-6}$
$Q_4 =$	312.55×10^{-6}	$Q_{11} = 12769.9$	$\times 10^{-6}$
$*Q_5 =$	7.5×10^{-6}	$Q_{12} =$ 89.3	$\times 10^{-6}$
$Q_6 =$	3750.6×10^{-6}	$Q_{13} =$ 89.3	$\times 10^{-6}$
$Q_7 =$	13395.0×10^{-6}	$***Q_{14} =$ 397.83	$\times 10^{-6}$

* equivalent operating time t = 15 cycles.

** Q_{10} (S.O. Valve with a manual override) is found by taking the reliability of a solenoid valve in parallel with a manual override (operating time t = 15 cycles)

$$Q_{10} = Q_{10A} \times Q_{10B}$$

$$Q_{10} = 0.01925 \times 10^{-6}$$



$Q_{10A} = 1275.0 \times 10^{-6}$

$Q_{10B} = 15.0 \times 10^{-6}$

*** $L_{14} = (0.54/\text{hours}) \times (1.5 \text{ lines and fittings/part})$ (11 parts) $L_{14} = 8.91 \times 10^{-6}$

****The relief valve would leak into the line causing an abort and would have no effect on crew safety.

2.4.1.1 Basic Tank Design #1 Reliability for Crew Safety

The ascent tank reliability is based on the block diagram of Figure 8.

$$Q = Q_1 + Q_2 + Q_3Q_{12} + Q_4Q_{13} + \{1-(R_7 [R_8(1-Q_8Q_{11}) + Q_5R_6 (1-Q_{11}Q_8)] + Q_7R_6R_8)\} + Q_9 + Q_{10} + Q_{14}$$

$Q = 0.001016927$

$R = 1-Q$

$R = .9989831$

BASIC TANK DESIGN
2

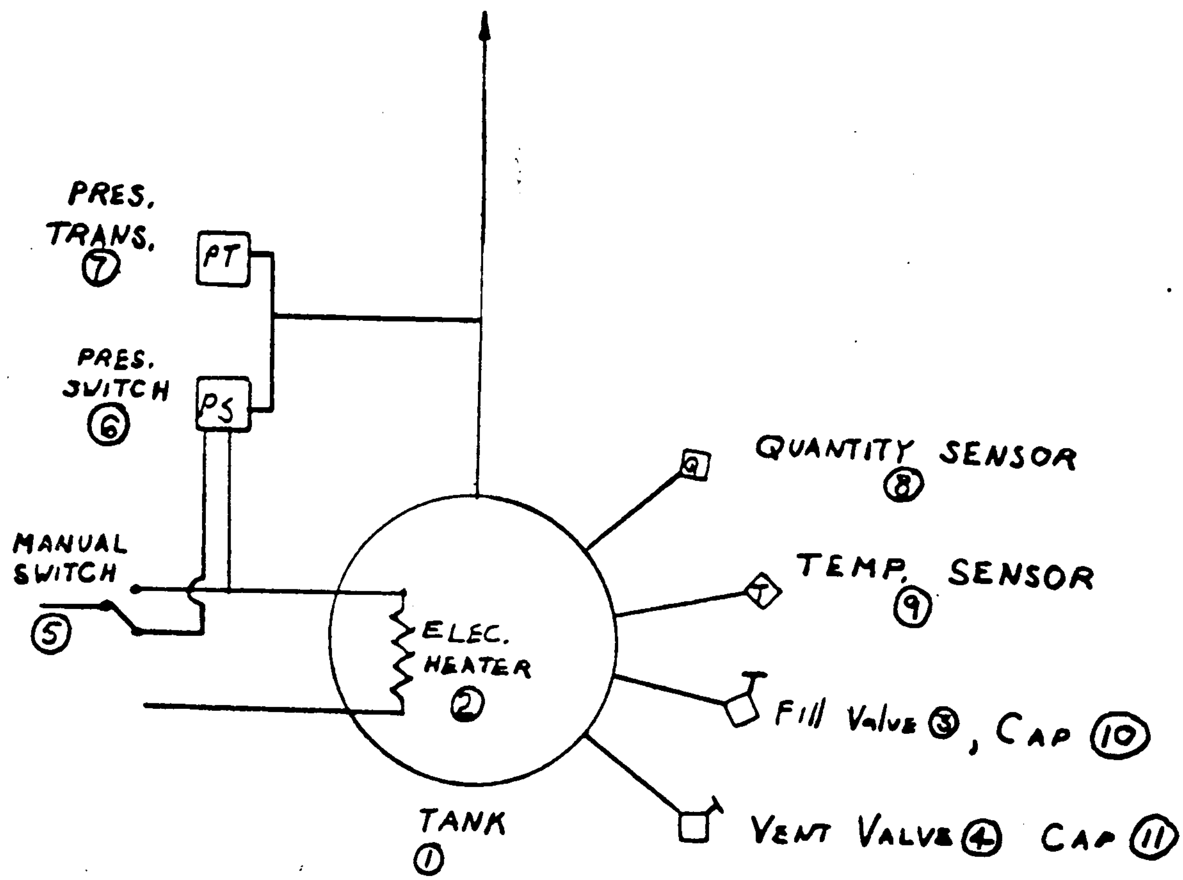


FIGURE 9

BASIC TANK DESIGN

No. 2

RELIABILITY DIAGRAM

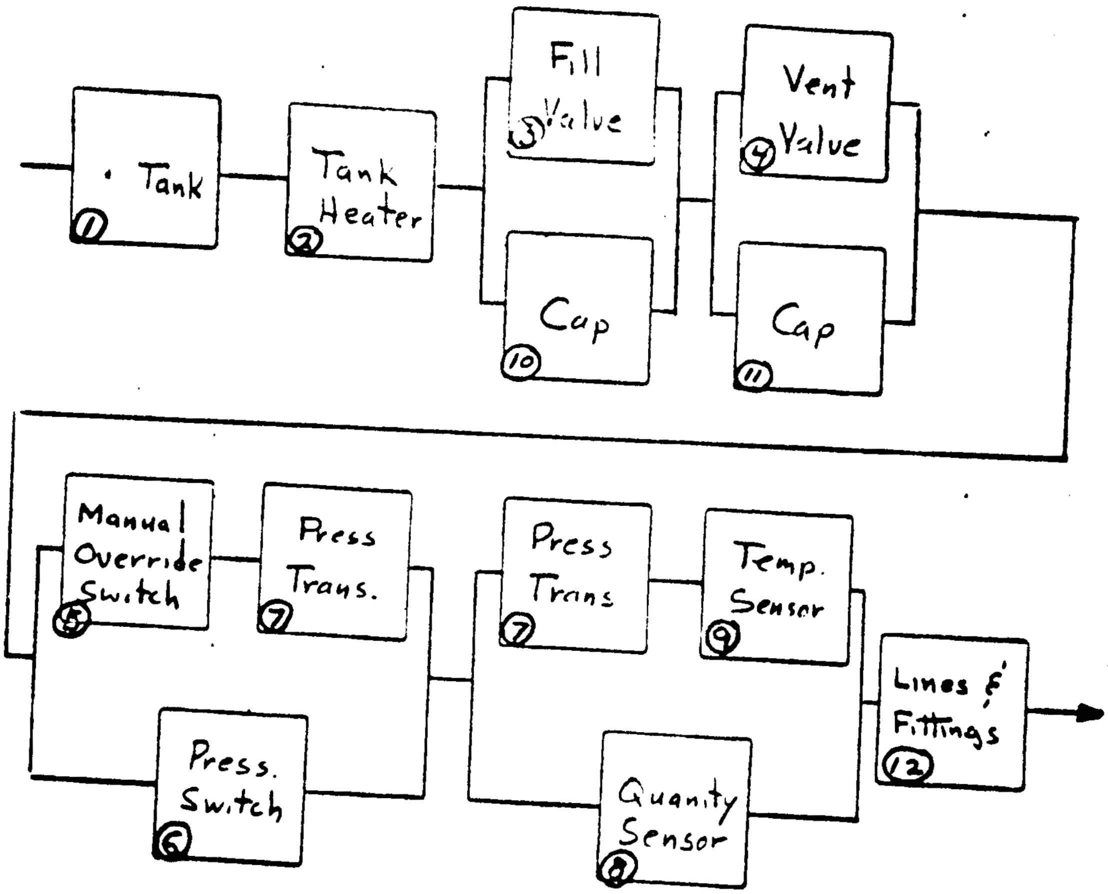


Figure 10

2.4.2 Basic Tank Design #2 Part Unreliabilities for Crew Safety

This tank, Figure 9, is used in : 1) the descent hydrogen and oxygen staged configurations , and 2) the unstaged oxygen configuration. For crew safety we are not considered with the descent tankage. Consequently its operating time is $t = 0$, resulting in an $R = 1$. However, for the ascent tankage we have an operating time $t = 44.65$ hours for crew safety.

Failure rates (L) are given per million hours or per million cycles of operation. $Q_n = (L_n) \times (t)$

$Q_1 = 89.3 \times 10^{-6}$ $Q_7 = 13395.0 \times 10^{-6}$

$Q_2 = 133.95 \times 10^{-6}$ $Q_8 = 13395.0 \times 10^{-6}$

$Q_3 = 312.55 \times 10^{-6}$ $Q_9 = 12769.9 \times 10^{-6}$

$Q_4 = 312.55 \times 10^{-6}$ $Q_{10} = 89.3 \times 10^{-6}$

$^*Q_5 = 7.5 \times 10^{-6}$ $Q_{11} = 89.3 \times 10^{-6}$

$Q_6 = 3750.6 \times 10^{-6}$ $^{**}Q_{12} = 325.498 \times 10^{-6}$

* equivalent operating time t = 15 cycles.

** $L_{12} = (0.54/\text{hours}) \times (1.5 \text{ lines and fittings/part}) \times (9 \text{ parts}) = 7.29 \times 10^{-6}$

2.4.2.1 Basic Tank Design #2 Reliability for Crew Safety

The Tank Reliability is based on the block diagram of Figure 10.

$$Q = Q_1 + Q_2 + Q_3Q_{10} + Q_4Q_{11} + \left\{1-R_7\left[R_5(1-Q_8Q_9) + Q_5R_6(1-Q_9Q_8)\right] + Q_7R_6R_8\right\} + Q_{12}$$

$$Q = 946.6338 \times 10^{-6}$$

$$R = 1 - Q = .9990534$$

3.1 Mission Success

To evaluate mission success a consistant set of ground rules are necessary to determine what constitutes abort. The first criterion that we consider is: abort after the failure, for which the next failure will kill the crew. However, this may not always be valid. If the crew safety reliability of the remaining system is still very high, we may still not abort, even if the next failure may kill the crew. The reverse, i.e. abort may be necessary if the remaining crew safety is low, even though the next failure may not kill the crew, is also true. Because of the limited scope of this effort only the first criterion was applied for mission success.

In applying this first criterion, it is important to note that orbital contingency was considered as a failure. This is in agreement with LMO-540-134 which originated from the systems integration group.

In addition, due to the workstatement, the GOX tank must operate for mission success.

On the next few pages there are block representations of each configuration. The charts below each configuration answer the question: is an abort necessary? The question is asked of each component, and combinations of components in various phases.

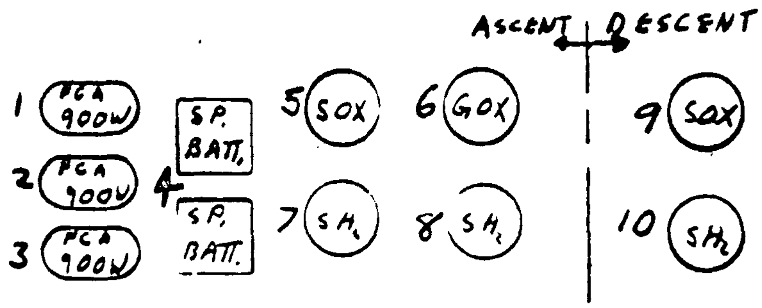
The phases considered were: 1) earth-launch to separation; 2) separation to lunar touch-down; 3) lunar touch-down to 4 hour lunar stay. To obtain a mission success, a 4 hour lunar stay is all that is necessary to consider. The reliability for return to the CSM is merely crew safety reliability.

The formulas for mission success in each configuration can be broken up into 3 separate series boxes (see 3.2): 1) O_2 system, 2) H_2 system, and 3) fuel cells and battery combination.

As an example of how the O_2 system was handled consider configuration 1 where $R_{O2} = R(5_3)\,R(6_3)\,R(9_2)$. It is obvious that the ascent SOX tank, through 3 phases, is in series with the GOX tank, through 3 phases, which is in turn in series with the descent tank through 2 phases. The same type reasoning can be applied to hydrogen system and also to the Fuel Cell & Battery combination.

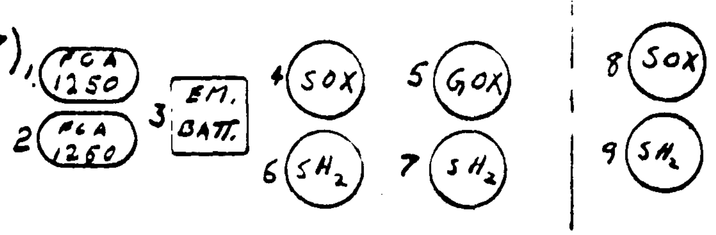
Table 2 summarizes the reliability of each of these building blocks. The calculations of these building blocks can be found in the rear of this section (3.3)

1-4)



FAILED COMPONENTS / WHEN FAILED	1	2	3	4	5	6	7	8	9	10	1+2	1+3	2+3	9+10	9+10+1∩2∩3
PHASE 1: EARTH-LAUNCH TO SEPARATION	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
PHASE 2: SEPARATION TO LUNAR TOUCH-DOWN	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
PHASE 3: LUNAR TOUCH-DOWN TO 4-HR. STAY	NO	NO	NO	NO	YES	YES	YES	YES	NO	NO	YES	YES	YES	NO	NO

5-7)



	1	2	3	4	5	6	7	8	9	1+2	1+3	2+3	8+9	8+9+(1∩2∩3)
PHASE 1	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
PHASE 2	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
PHASE 3	NO	NO	NO	YES	YES	YES	YES	NO	NO	YES	YES	YES	NO	NO

8-10)

1 FCA 1250W
2 FCA 1250W
3 EM BATT
4 SOX
5 GOX
6 SH_2
7 SOX
8 SH_2

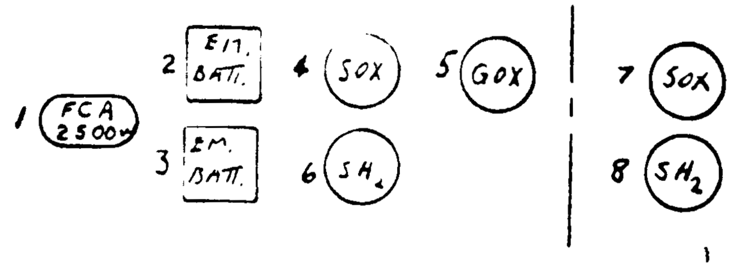
	1	2	3	4	5	6	7	8	1+2	7+8	7+8+(1 or 2)
PHASE 1	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES
PHASE 2	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES
PHASE 3	NO	NO	YES	YES	YES	YES	NO	NO	YES	NO	NO

11-13)

1 FCA 2500W
2 EM BATT.
3 SOX
4 GOX
5 SH_2
6 SOX
7 SH_2

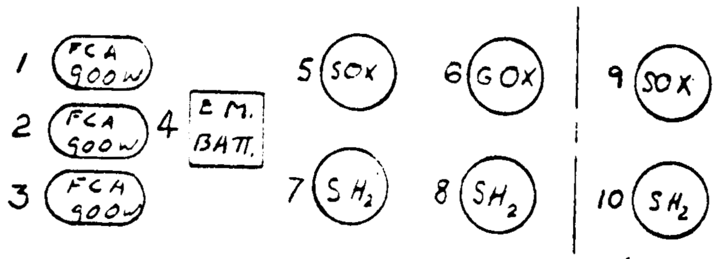
	1	2	3	4	5	6	7	6+7
PHASE 1	YES	YES	YES	YES	YES	YES	YES	YES
PHASE 2	YES	YES	YES	YES	YES	YES	YES	YES
PHASE 3	YES	YES	YES	YES	YES	NO	NO	NO

14-16)



	1	2	3	4	5	6	7	8	2+3	7+8	7+8+(2 or 3)
PHASE 1	Y	NO	NO	Y	Y	Y	YES	YES	YES	YES	YES
PHASE 2	E	NO	NO	E	E	E	YES	YES	YES	YES	YES
PHASE 3	S	NO	NO	S	S	S	NO	NO	YES	NO	NO

17-19)



	1	2	3	4	5	6	7	8	9	10	9+10	1+2 or 1+3 or 2+3	4+1 or 4+2 or 4+3	1+2+3 or 1+2+4 or 1+3+4 or 2+3+4
PHASE 1	NO	NO	NO	NO	Y	Y	Y	Y	YES	YES	YES	NO	NO	YES
PHASE 2	NO	NO	NO	NO	E	E	E	E	YES	YES	YES	NO	NO	YES
PHASE 3	NO	NO	NO	NO	S	S	S	S	NO	NO	NO	NO	NO	YES

3.2 MISSION SUCCESS RELIABILITY CALCULATIONS

1-2*)

$$R = \left\{R(1_3)\left[1 - Q(2_3)\,Q(3_3)\right] + Q(1_3)\left[R(2_3)R(3_3)\right]\right\} \times R(5_3) \times R(6_3) \times$$
$$\times R(7_3) \times R(8_3) \times R(9_2) \times R(10_2)$$

WHERE: $R(5_3)\,R(6_3)\,R(9_2) = R$ OF Oxygen SYS.

$R(7_3)\,R(8_3)\,R(10_2) = R$ OF Hydrogen SYS.

$\{\ \} = R$ OF 2 OF 3 FUEL CELLS

$R = .9802611$

3)

$$R = \left\{R(1_3)\left[1 - Q(2_3)\,Q(3_3)\right] + Q(1_3)\left[R(2_3)\,R(3_3)\right]\right\} R(5_3)\; R(6_3)$$
$$R(7_3)\; R(8_3)\; R(9_2)$$

WHERE: $R(5_3)\,R(6_3)\,R(9_2) = R$ OF O_2 SYS.

$R(7_3)\,R(8_3) = R$ OF H_2 SYS.

$\{\ \} = R$ OF 2 OF 3 FUEL CELLS

$R = .9827335$

NOTE: SUBSCRIPT INDICATES HOWMANY PHASES PART MUST OPERATE FOR.

* CONFIGURATION 1 + 2 ARE IDENTICAL FROM A RELIABILITY POINT OF VIEW.

4) $R = \{R(1_3)[1 - Q(2_3)Q(3_3) + Q(1_3)[R(2_3)R(3_3)]]\}\, R(5_3)R(6_3)R(7_3)R(8_3)$

WHERE: $R(5_3)R(6_3)$ = R OF O_2 SYS.

$R(7_3)R(8_3)$ = R OF H_2 SYS.

{ } = R OF 2 OF 3 FUEL CELLS

R = .9856921

5) $R = \{R(1_3)[1 - Q(2_3)Q(3_3) + Q(1_3)[R(2_3)R(3_3)]]\}\, R(4_3)R(5_3)R(6_3)$
$R(7_3)R(8_2)R(9_2)$

WHERE: $R(4_3)R(5_3)R(8_2)$ = R OF O_2 SYS

$R(6_3)R(7_3)R(9_2)$ = R OF H_2 SYS.

{ } = R OF FUEL CELL + BATTERY COMBINATION.

R = .9802648

6) $R = \{R(1_3)[1 - Q(2_3)Q(3_3) + Q(1_3)[R(2_3)R(3_3)]]\}\, R(4_3)R(5_3)R(6_3)R(7_3)R(8_2)$

WHERE: $R(4_3)R(5_3)R(8_2)$ = R OF O_2 SYS.

$R(6_3)R(7_3)$ = R OF H_2 SYS.

{ } = R OF FUEL CELL + BATT. COMBINATION

R = .9827371

7) $R = \{R(1_3)[1 - Q(2_3)\,Q(3_3) + Q(1_3)[R(2_3)R(3_3)]]\}R(4_3)\,R(5_3)\,R(6_3)\,R(7_3)$

WHERE: $R(4_3)\,R(5_3)$ = R OF O_2 SYS.

$R(6_3)\,R(7_3)$ = R OF H_2 SYS.

$\{\}$ = R OF F.C.A + BATT. COMBINATION.

$R = .9856958$

8) $R = [1 - Q(1_3)\,Q(2_3)]\;R(3_3)\,R(4_3)\,R(5_3)\,R(6_3)\;R(7_2)\,R(8_2)$

WHERE: $R(4_3)\,R(5_3)\,R(7_2)$ = R OF O_2 SYS.

$R(6_3)\,R(8_2)$ = R OF H_2 SYS.

$[1 - Q(1_3)Q(2_3)]R(3_3)$ = R OF F.C.A. + BATT.

$R = .9819296$

9) $R = [1 - Q(1_3)\,Q(2_3)]\,R(3_3)\,R(4_3)\,R(5_3)\,R(6_2)\;R(7_2)$

WHERE: $R(4_3)\,R(5_3)\,R(7_2)$ = R OF O_2 SYS.

$R(6_2)$ = R OF H_2 SYS.

$[1 - Q(1_3)Q(2_3)]\,R(3_3)$ = R OF FCA + BATT.

$R = .9842758$

10) $R = [1 - Q(1_3)Q(2_3)]R(3_3)\,R(4_3)\,R(5_3)\,R(6_3)$

WHERE: $R(4_3)\,R(5_3) = R$ OF O_2 SYS.

$R(6_3) = R$ OF H_2 SYS.

$[1 - Q(1_3)Q(2_3)]R(3_3) = R$ OF FCA & BATT.

$R = .9872391$

11) $R = R(1_3)R(2_3)R(3_3)\,R(4_3)\,R(5_3)\,R(6_2)\,R(7_2)$

WHERE: $R(1_3)R(2_3) = R$ OF BATT & FCA

$R(3_3)\,R(4_3)\,R(6_2) = R$ OF O_2 SYS.

$R(5_3)\,R(7_2) = R$ OF H_2 SYS.

$R = .9617332$

12) $R = R(1_3)R(2_3)R(3_3)\,R(4_3)\,R(5_3)\,R(6_3)$

WHERE: $R(1_3)\,R(2_3) = R$ OF BATT & FCA

$R(6_3)R(3_3)\,R(4_3) = R$ OF O_2 SYS.

$R(5_3) = R$ OF H_2 SYS.

$R = .9640312$

13) $R = R(1_3)\,R(2_3)\,R(3_3)\,R(4_3)\,R(5_3)$

WHERE: $R(1_3)R(2_3) = R$ OF FCA & BATT.

$R(3_3)\,R(4_3) = R$ OF O_2 SYS.

$R(5_3) = R$ OF H_2 SYS.

$R = .9669335$

14) $R = R(1_3)[1-Q(2_1)Q(3_1)]R(4_1)R(5_3)R(6_3)R(7_2)R(9_2)$

WHERE: $R(1_3)[1-Q(2_1)Q(3_1)] = R$ OF FCA + BATTS.

$R(4_2)R(5_3)R(7_2) = R$ OF O_2 SYS.

$R(6_3)R(9_2) = R$ OF H_2 SYS.

$R = .9652917$

15) $R = R(1_3)[1-Q(2_3)Q(3_1)]R(4_3)R(5_3)R(6_3)R(7_2)$

WHERE: $R(1_3)[1-Q(2_1)Q(3_1)] = R$ OF FCA + BATT.

$R(4_3)R(5_3)R(7_2) = R$ OF O_2 SYS.

$R(6_3) = R$ OF H_2 SYS.

$R = .9675981$

16) $R = R(1_3)[1-Q(2_3)Q(3_3)]R(4_3)R(5_3)R(6_3)$

WHERE: $R(1_3)[1-Q(2_3)Q(3_3)] = R$ OF BATT + FCA

$R(4_3)R(5_3) = R$ OF O_2 SYS.

$R(6_3) = R$ OF H_2 SYS.

$R = .9705111$

17) $$R = \left\{R(1_3)\left[1 - Q(2_3)\,Q(3_3)\,Q(4_3)\right] + Q(1_3)\left[R(2_3)\left(1 - Q(3_3)\,Q(4_3)\right) + Q(2_3)\,R(3_3)\,R(4_3)\right]\right\} \cdot R(5_3)\,R(6_3)\,R(7_3)\,R(8_3)\,R(9_2)\,R(10_2)$$

WHERE; $\{\ \}$ = R OF 3 F.C.A + BATT COMBINATION.

$R(5_3)\,R(6_3)\,R(9_2)$ = R OF O_2 SYS.

$R(7_3)\,R(8_3)\,R(10_2)$ = R OF H_2 SYS.

R = .9815273

18) $R = \{\text{see } 17\}\ R(5_3)\,R(6_3)\,R(7_3)\,R(8_3)\,R(9_2)$

WHERE: $\{\ \}$ = R OF F.C.A. + BATT. COMBINATION.

$R(5_3)\,R(6_3)\,R(9_2)$ = R OF O_2 SYS.

$R(7_3)\,R(8_3)$ = R OF H_2 SYS.

R = .9840028

19) $R = \{\text{see } 17\}\ R(5_3)\,R(6_3)\,R(7_3)\,R(8_3)$

WHERE: $\{\ \}$ = R OF F.C.A. + BATT. COMBINATION.

$R(5_3)\,R(6_3)$ = R OF O_2 SYS.

$R(7_3)\,R(8_3)$ = R OF H_2 SYS.

R = .9869653

TABLE 4

Part Unreliabilities for Mission Success ($\times 10^{-6}$)

Part	Phase 1 (t=90.45/hr.)	Phase 1 & 2 (t=94.617/hr.)	Phase 1&2&3 (t=135.3/hr.)
Basic Tank #1	2060.05	2154.95	3081.53
Basic Tank #2	1917.65	2005.99	2868.52
Heat Exchanger	253.26	264.93	378.84
Check Valve	4703.40		7035.60
Relief Valve (double)	73.84		88.91
Lines & Fittings			
4 Parts	293.06	306.56	438.37
5 Parts	366.32	383.20	547.97
6 Parts	439.58		657.56
Sol. S.O. & Manual Override	0.695		0.141
GOX	180.9		81.37
Disconnect	0.01		0.01

3.3.1 Staged O_2 - Mission Success

All success paths and cuts are based upon Figure 5. The part unreliabilities are given in Table 4.

Success Paths

$(1_3\ 2_3\ 4_3\ 5_3\ 7_3\ 8_3\ 10_3\ 13_3\ 14_3\ 20_3\ 21_3\ 9_2\ 11_2\ 22_2)$

$(1_3\ 2_3\ 4_3\ 5_3\ 7_3\ 8_3\ 10_3\ 12_3\ 20_3\ 21_3\ 22_3\ 9_2\ 11_2)$

Cuts

$(1_3)\ (2_3)\ (4_3)\ (5_3)\ (7_3)\ (8_3)\ (10_3)\ (20_3)\ (21_3)\ (9_2)\ (11_2)$

$(22_2)\ (13_3\text{-}12_3)\ (13_3\text{-}22_3)\ (14_3\text{-}12_3)\ (14_3\text{-}22_3)$

$$R = R(1_3)\,R(2_3)\,R(4_3)\,R(5_3)\,R(7_3)\,R(8_3)\,R(10_3)\,R(20_3)\,R(21_3)\,R(9_2)\,R(11_2)\,R(22_2)\left[1-Q(13_3)\,Q(12_3)\right]\left[1-Q(13_3)\times Q(22_3)\right]\left[1-Q(14_3)\,Q(12_3)\right]\left[1-Q(14_3)\,Q(22_3)\right]$$

$R = .99212402$

3.3.2 Unstaged O_2 - Mission Success

For mission success all parts are in series. The reliability is based upon Figure 6. The part unreliabilities are given in Table 4.

$$R = R(1_3)\,R(2_3)\,R(4_3)\,R(8_3)\,R(20_3)\,R(5_3)\,R(7_3)\,R(21_3)$$

$R = .9951109$

3.3.3 Fat Tanks Staged Hydrogen - Mission Success

All success paths and cuts are based upon Figure 1. The part unreliabilities are given in Table 4.

Success Paths:

$(1_3\ 2_3\ 4_3\ 5_3\ 7_3\ 8_3\ 9_3\ 11_3\ 13_3\ 20_3\ 21_3\ 10_2\ 22_2)$

$(1_3\ 2_3\ 4_3\ 5_3\ 7_3\ 8_3\ 9_3\ 11_3\ 12_3\ 20_3\ 21_3\ 10_2\ 22_2)$

Cuts

$(1_3)\ (2_3)\ (4_3)\ (5_3)\ (7_3)\ (8_3)\ (9_3)\ (11_3)\ (20_3)\ (21_3)\ (10_2)$

$(22_2)\ (12_3\text{-}13_3)$

3.3.3 (continued)

$$R = R(1_3)\,R(2_3)\,R(4_3)\,R(5_3)\,R(7_3)\,R(8_3)\,R(9_3)\,R(11_3)\,R(20_3)\,R(21_3)\,R(10_2)\,R(22_2)\left[1-Q(12_3)\,Q(13_3)\right]$$

$$R = .98933303$$

3.3.4 Fat Tanks Unstaged Hydrogen - Mission Success

For mission success all parts are in series. The reliability is based upon Figure 2. The part unreliabilities are given in Table 4.

$$R = R(1_3)\,R(2_3)\,R(4_3)\,R(5_3)\,R(7_3)\,R(8_3)\,R(9_3)\,R(20_3)\,R(21_3)$$

$$R = .99182828$$

3.3.5 Lean Tanks Staged Hydrogen - Mission Success

For mission success all parts are in series. The reliability is based upon Figure 3A. The part unreliabilities are given in Table 4.

$$R = R(1_3)\,R(2_3)\,R(5_3)\,R(6_2)\,R(7_3)$$

$$R = .993838568$$

3.3.6 Lean Tanks Unstaged Hydrogen - Mission Success

For mission success all parts are in series. The reliability is based upon Figure 4A. The part unreliabilities are given in Table 4.

$$R = R(1_3)\,R(2_3)\,R(3_3)$$

$$R = .9962132$$